April 11, 2016

The Role of Flow Diagnostic Techniques in Fan and Open Rotor Noise Modeling

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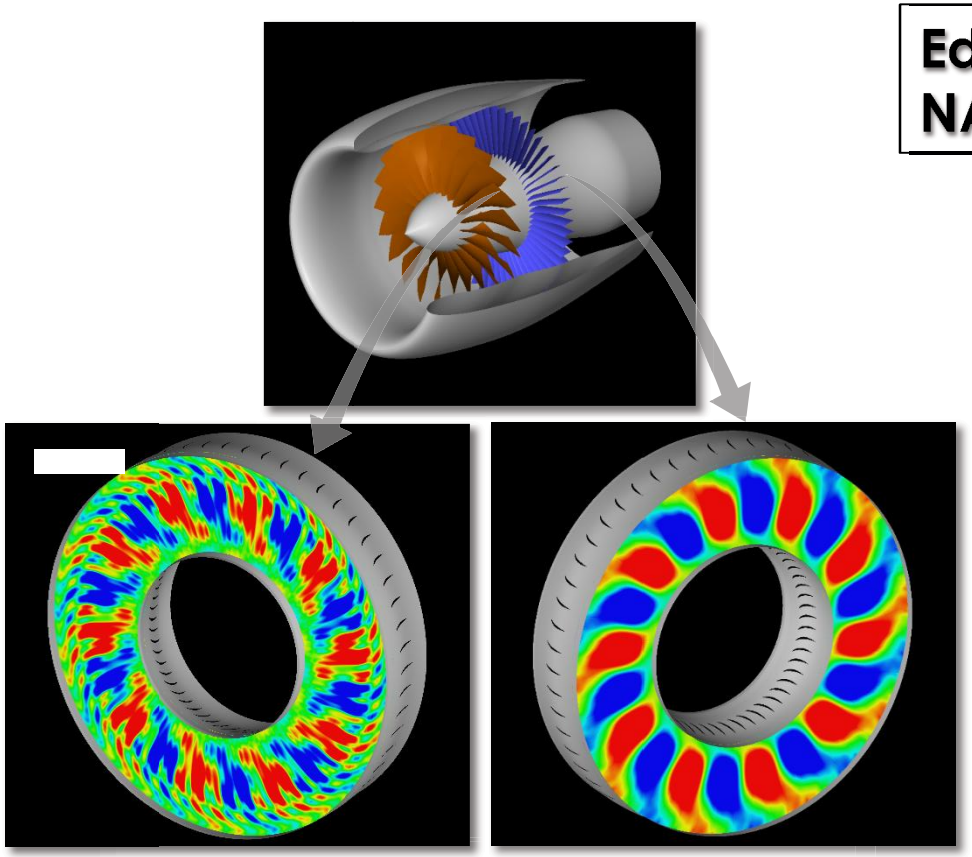
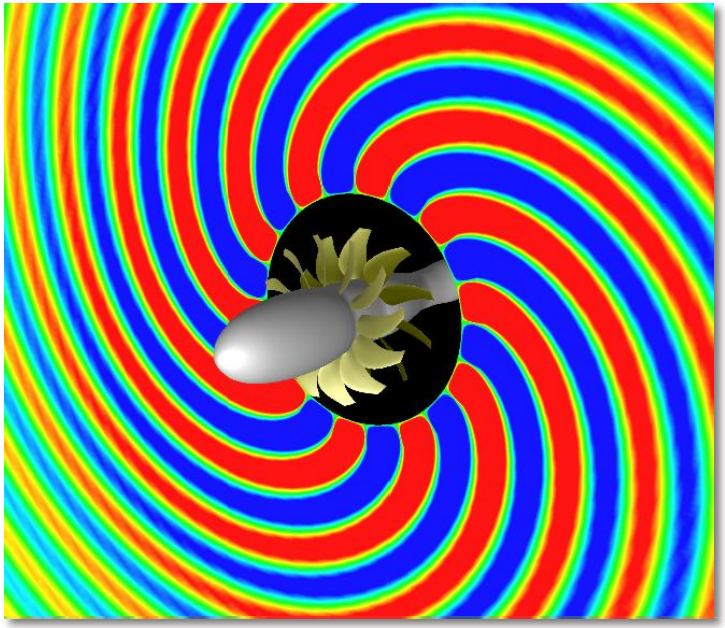


Fan/OGV Interaction Noise (2BPF Tone)



Aft Rotor Noise Wavefronts (BPF Tone)

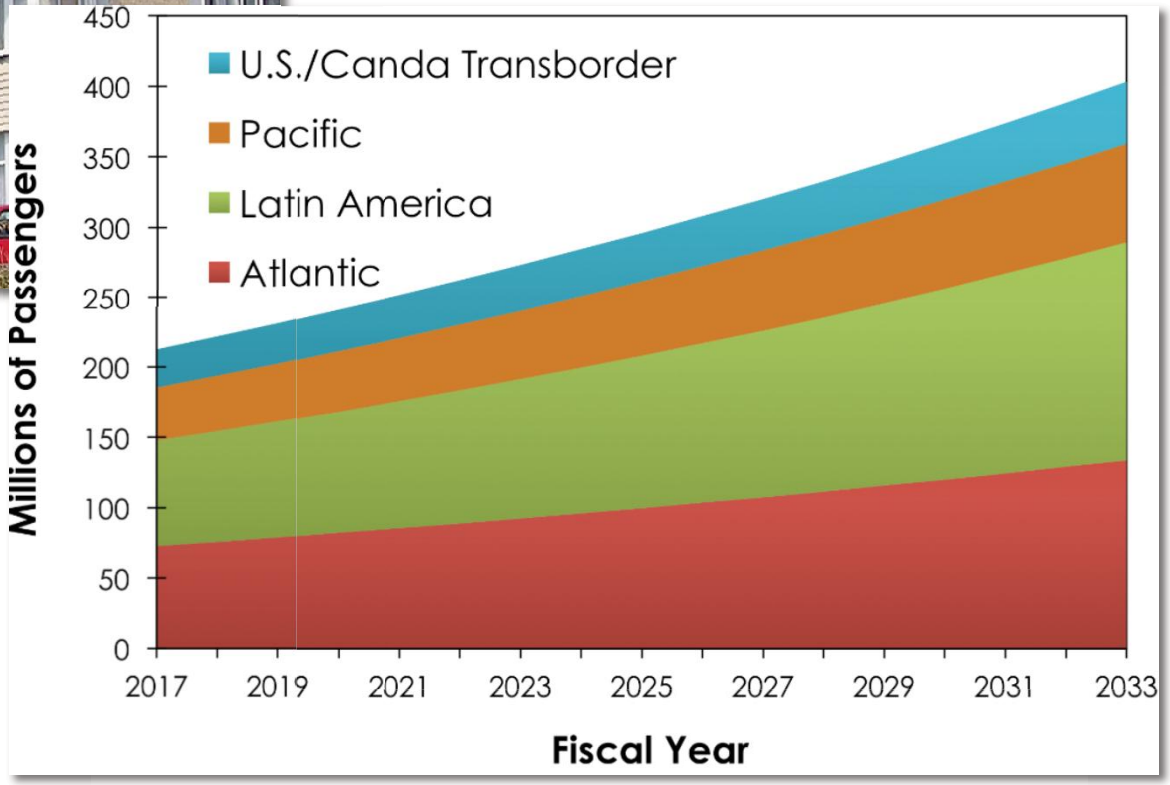
Outline

- Motivation
- Turbomachinery Noise Sources
- Noise Prediction Strategies
- Role of Diagnostic Techniques & Their Synergy With Prediction Tools
- Summary

Motivation

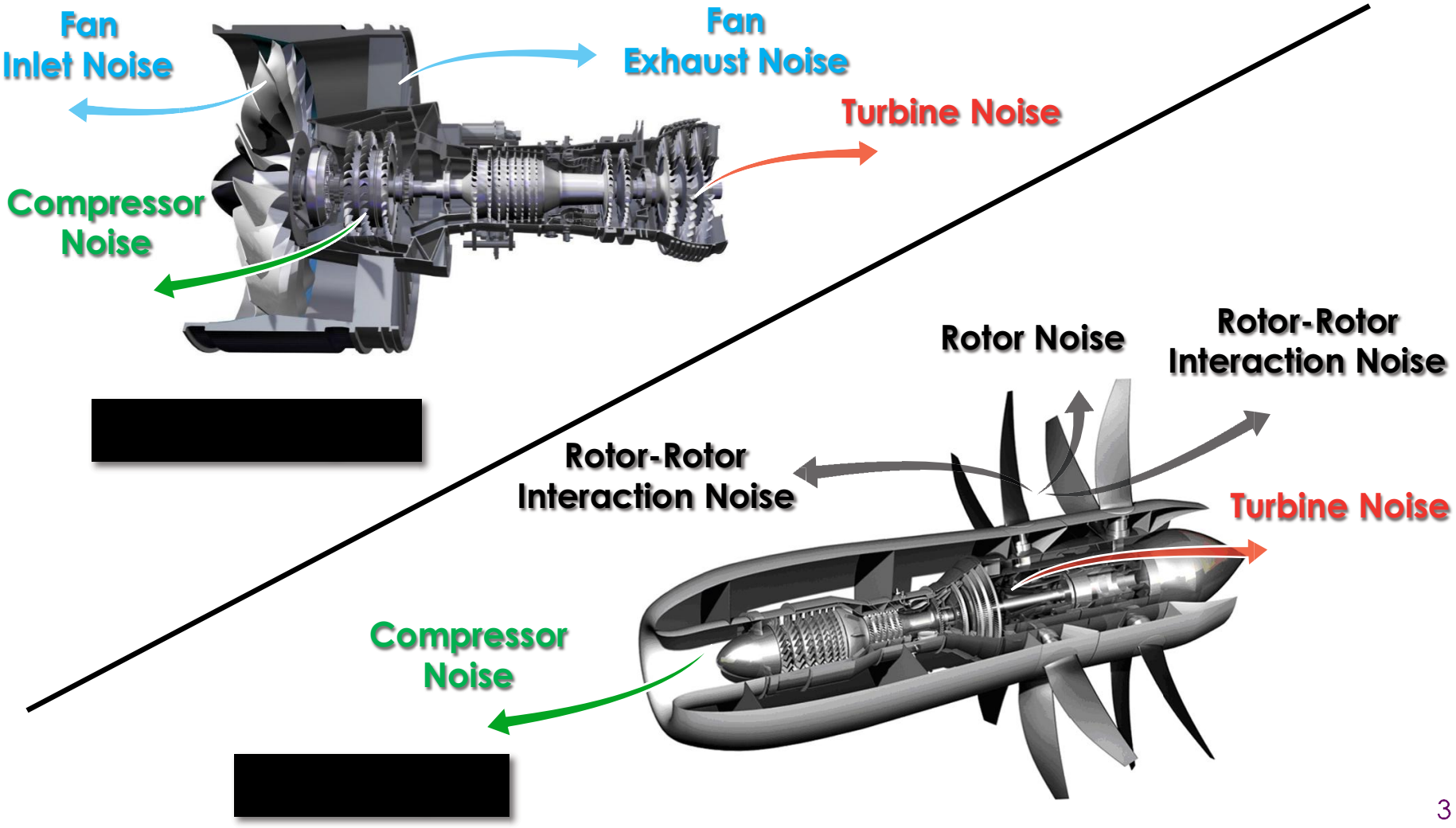
Environmental Impact of Aviation Noise

Projected Growth of Air Traffic in the U.S.



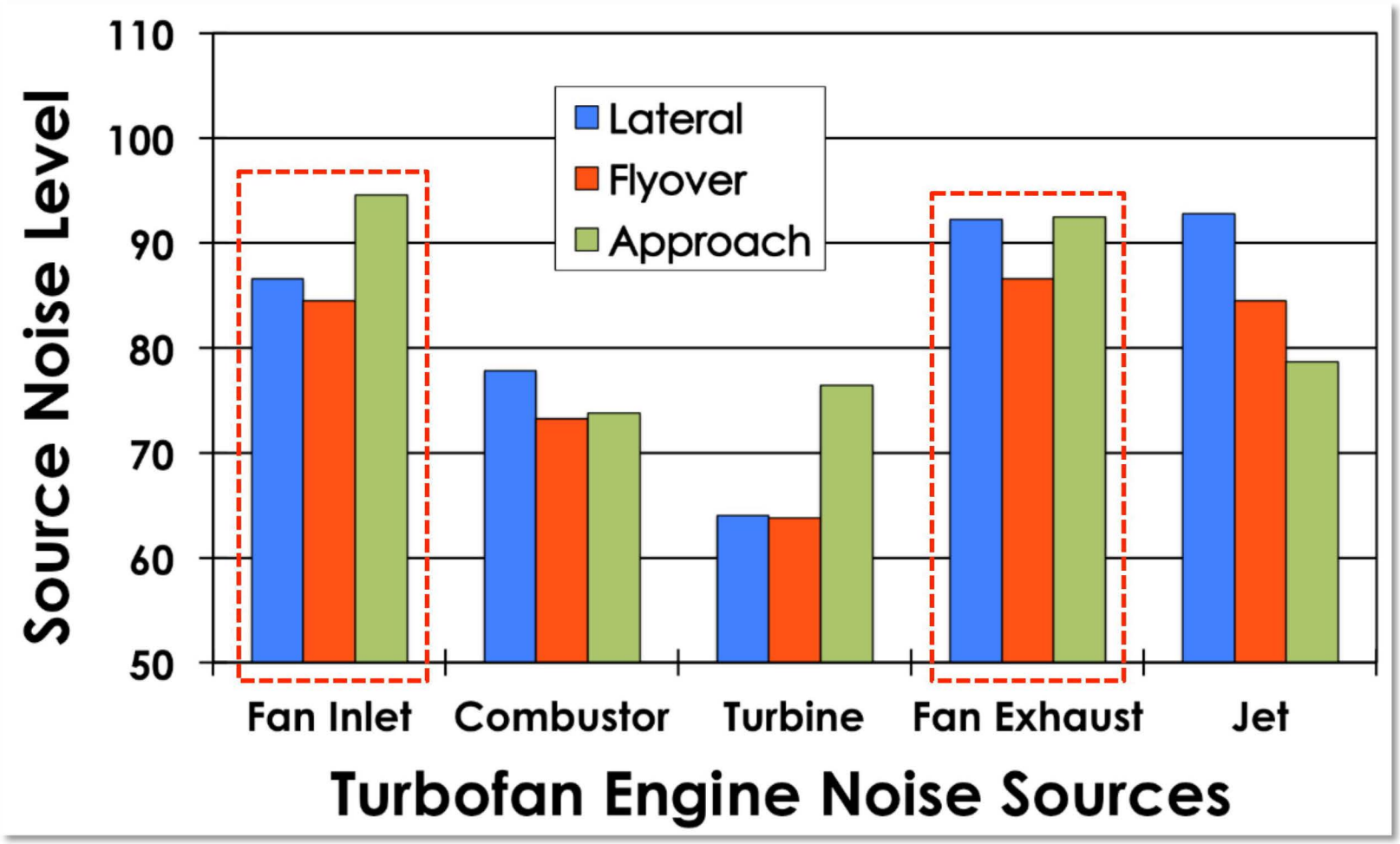
Turbomachinery Noise Sources

- Turbomachinery noise is a byproduct of the interaction of flow perturbations with rotating and stationary blade rows.



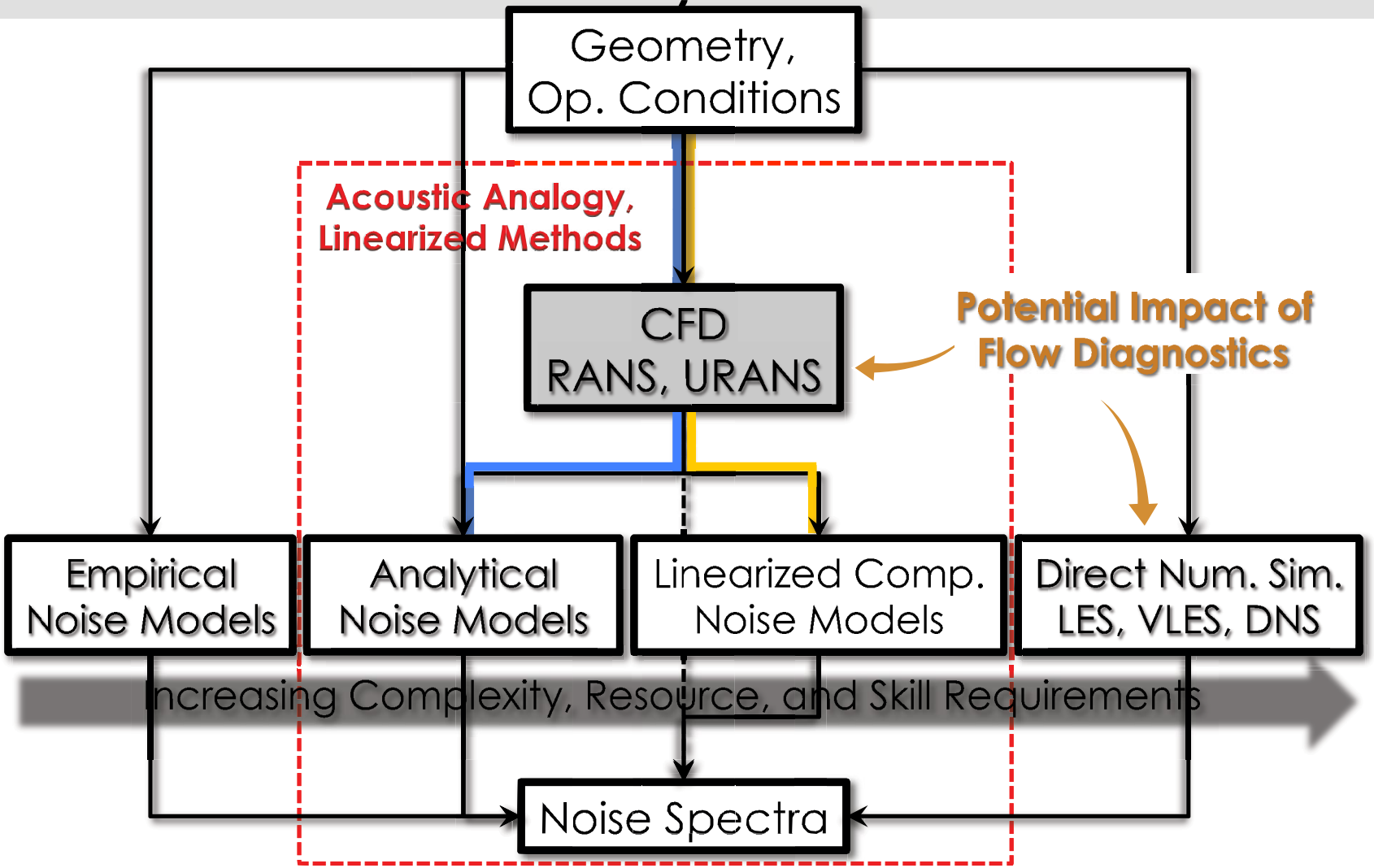
Hierarchy of Noise Sources

- **Propulsor (fan and open rotor) is a principle source of modern aircraft engine noise.**



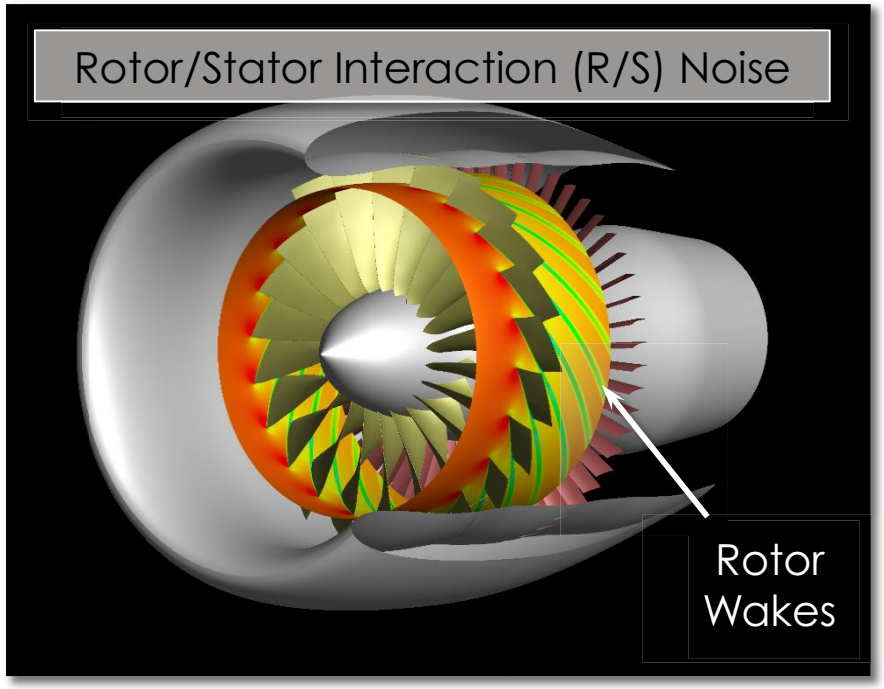
Noise Prediction Strategies

- **Noise prediction schemes run the gamut from empirical to direct simulation of unsteady flow inclusive of acoustics.**

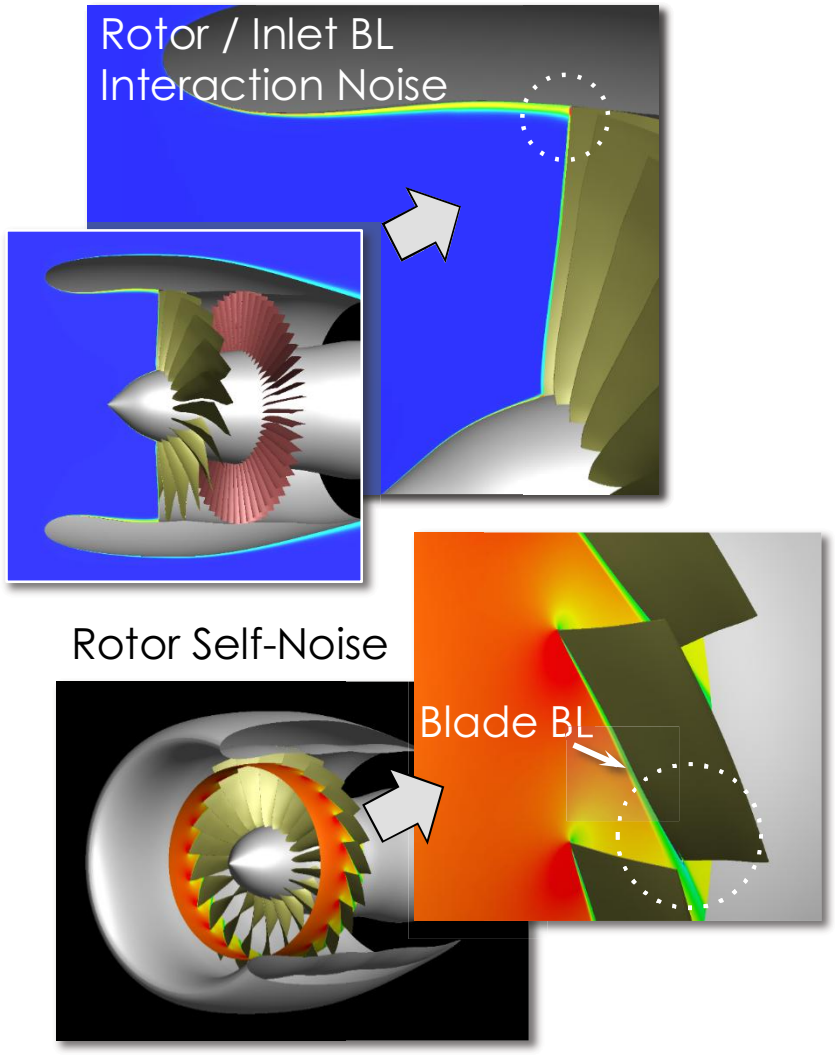


Fan Noise

- **Principal mechanism of fan noise is the interaction of the fan wake with the outlet guide vanes (OGVs).**



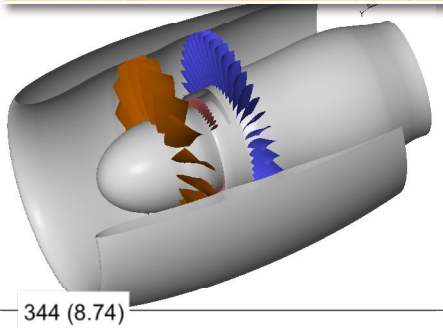
Tone & Broadband Noise Source

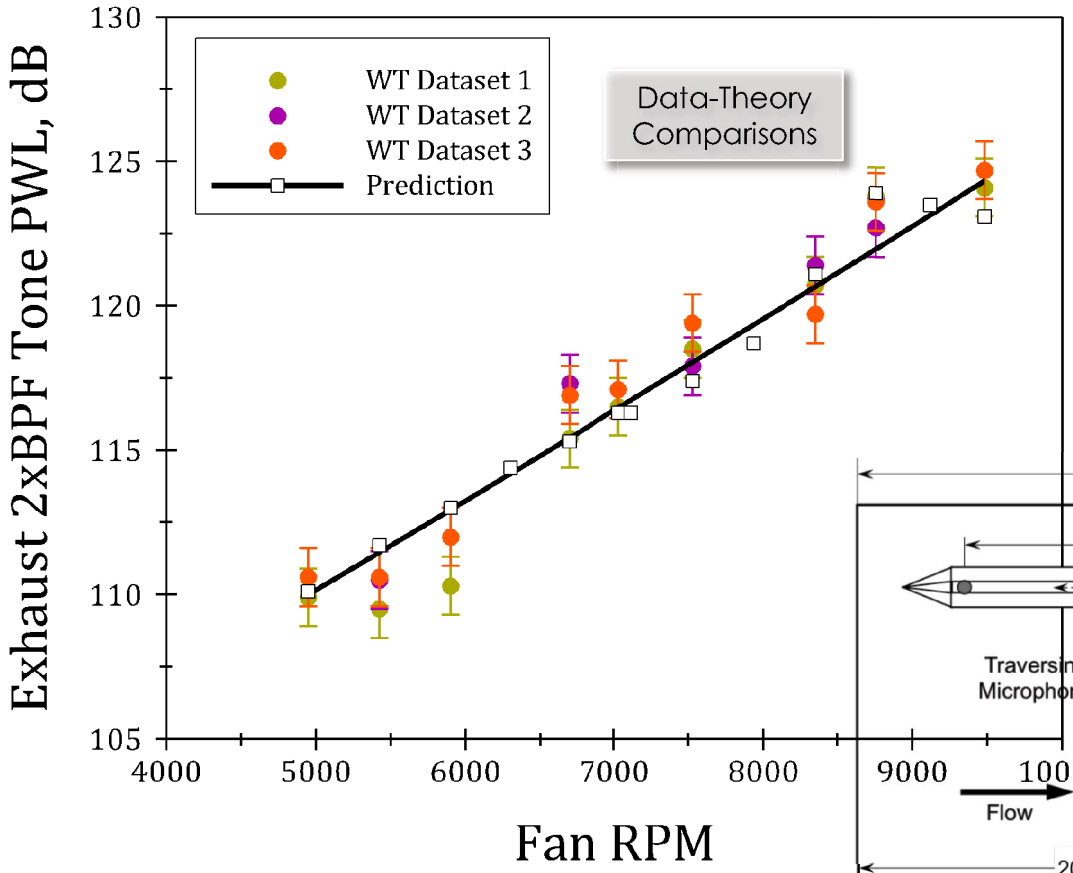


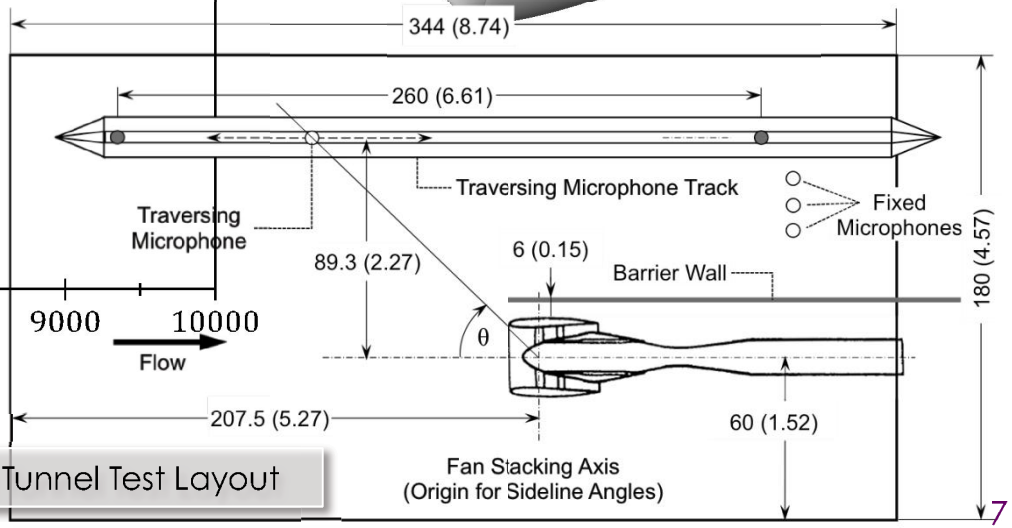
Broadband Noise Sources

Ex1: Fan R/S Tone Noise

- RANS for Aerodynamics
- Linearized Euler for Acoustics

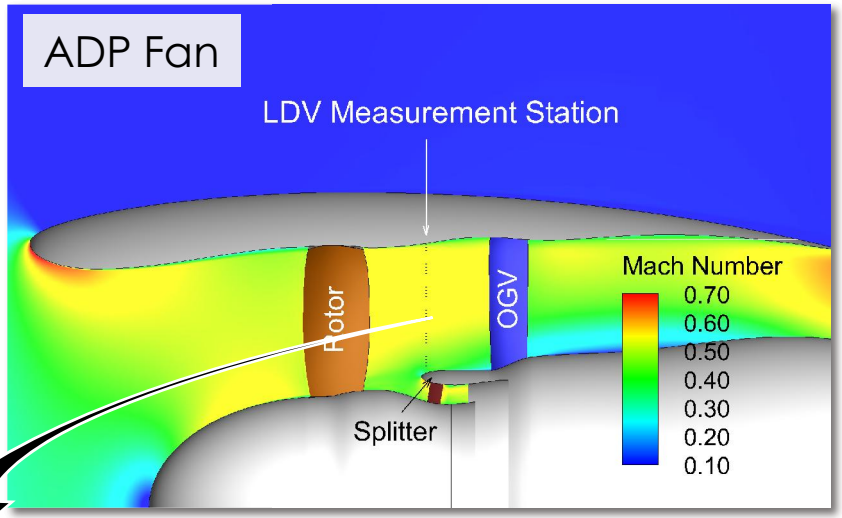




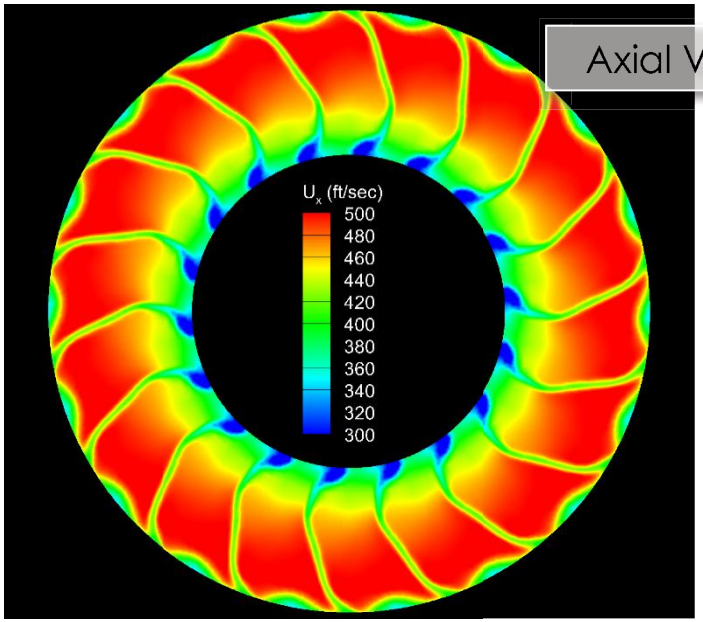


Fan Mean Wake Measurement

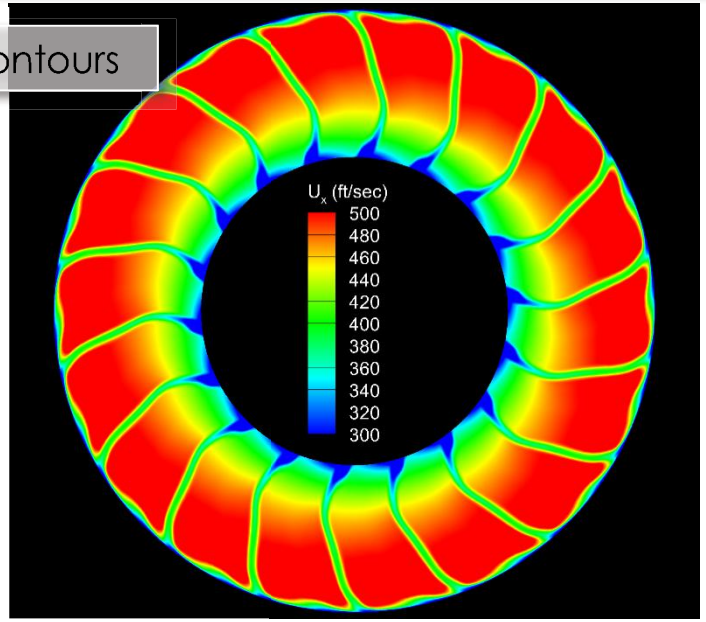
- **Using 2-component LDV technique, rotor flowfield downstream of the splitter lip was measured. The results were compared with the CFD.**



Axial Velocity Contours



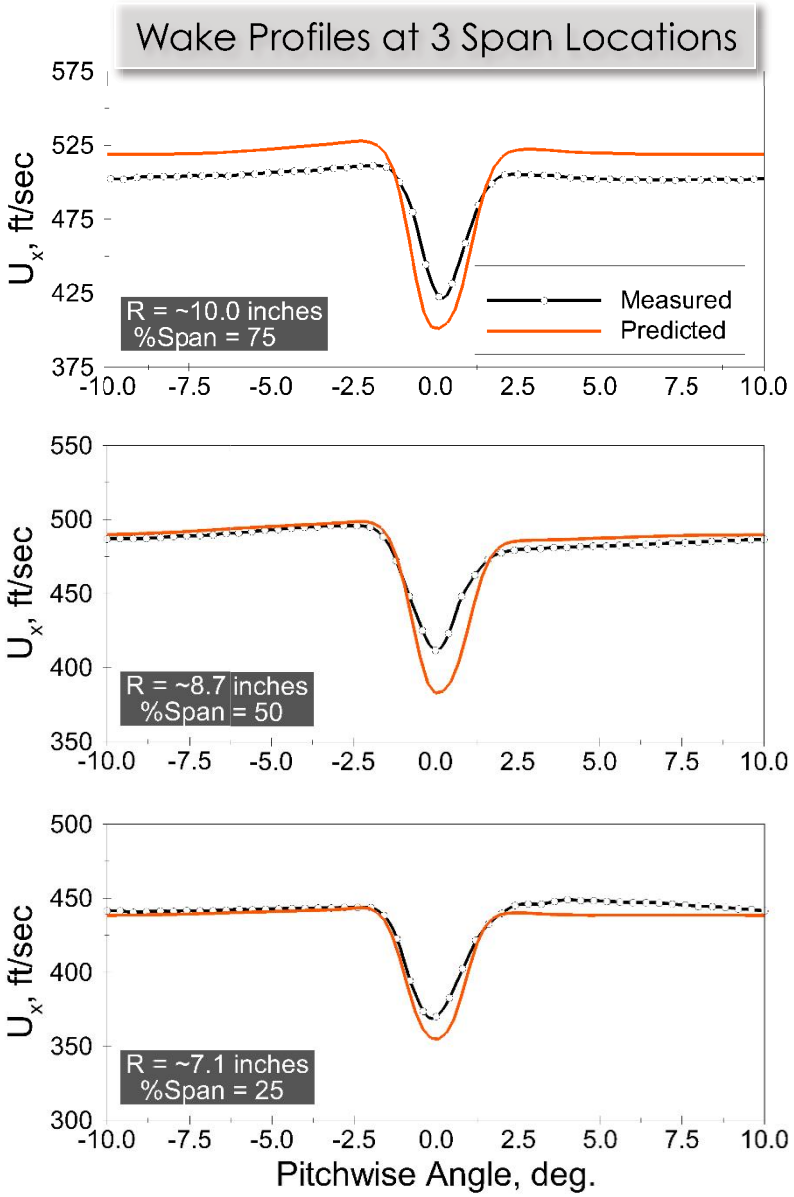
LDV



CFD (RANS)

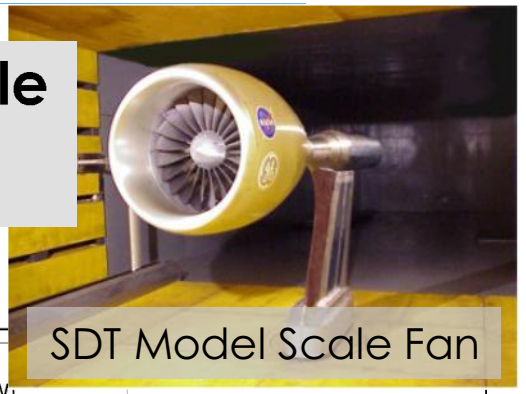
Comparison of Wake Profiles

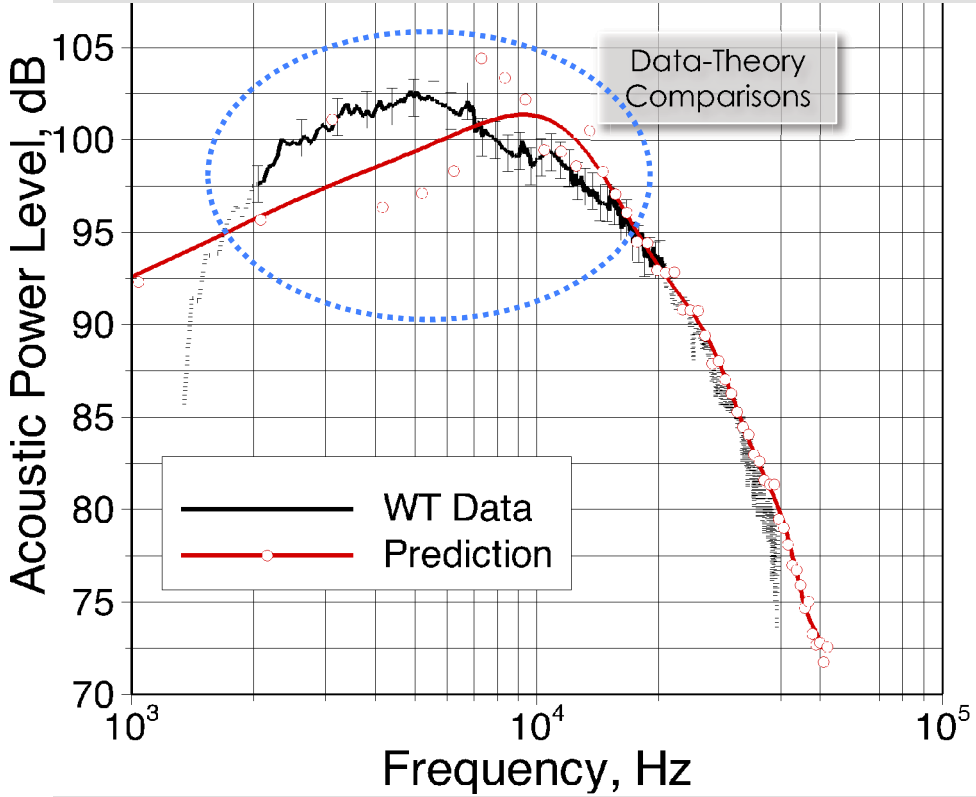
- **Data-theory comparisons for the wake profiles indicate that the harmonic content of wake were not consistently captured across the span by the RANS simulations.**

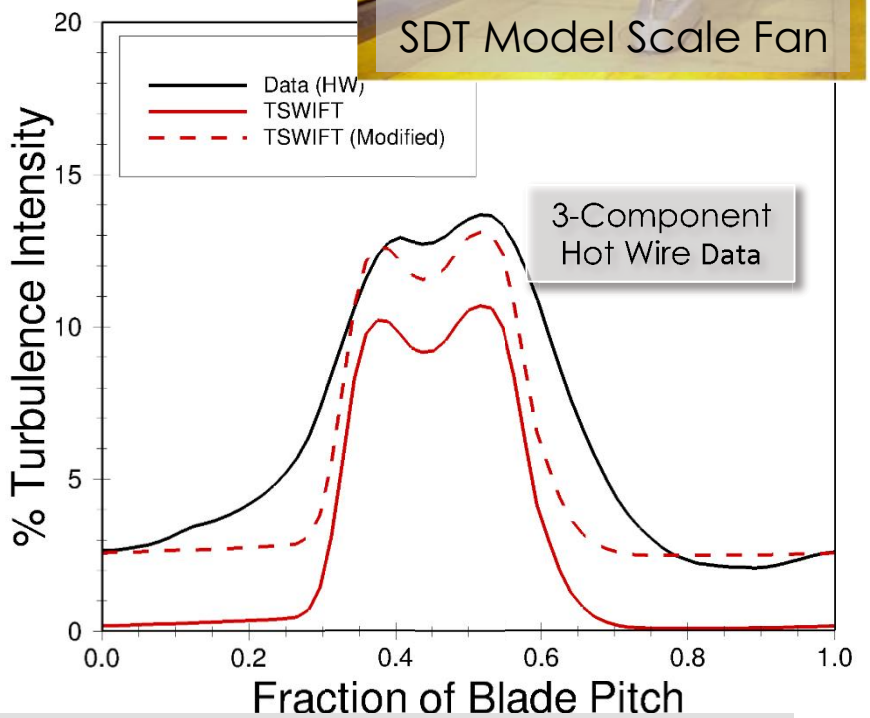


Ex2: Fan R/S Broadband Noise

- RANS for Turbulence Intensity & Length Scale
- Analytical for Acoustics



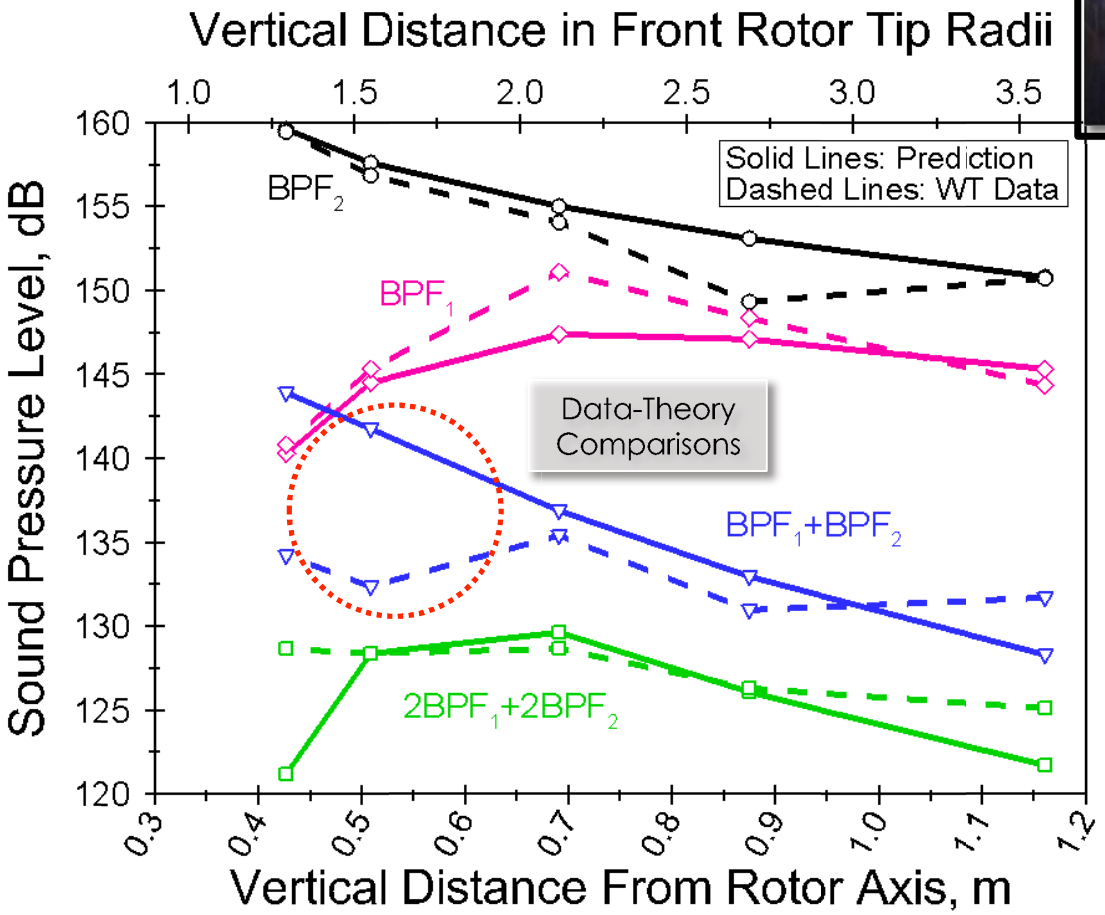


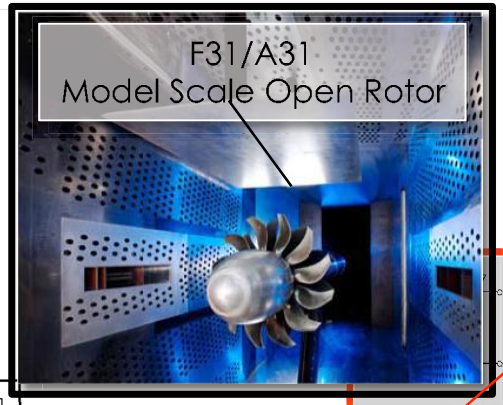


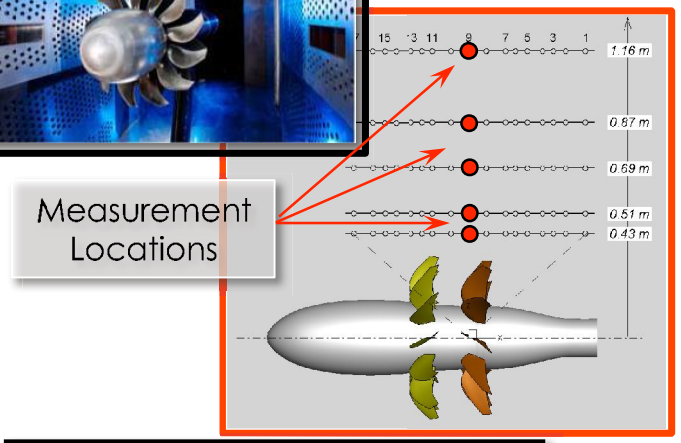
- Comparisons of turbulence intensity profiles indicate that RANS models under-predicted rotor turbulence levels.

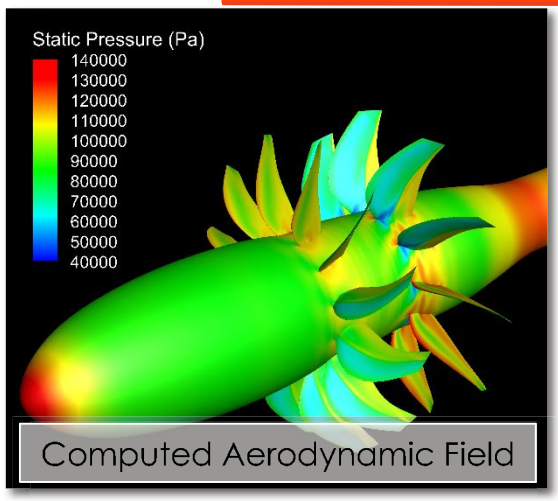
Ex2: Open Rotor Noise Modeling

- **URANS for Aerodynamics**
- **Acoustic Analogy for Acoustics**





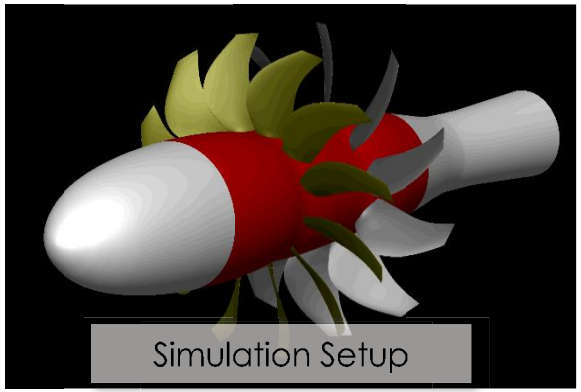


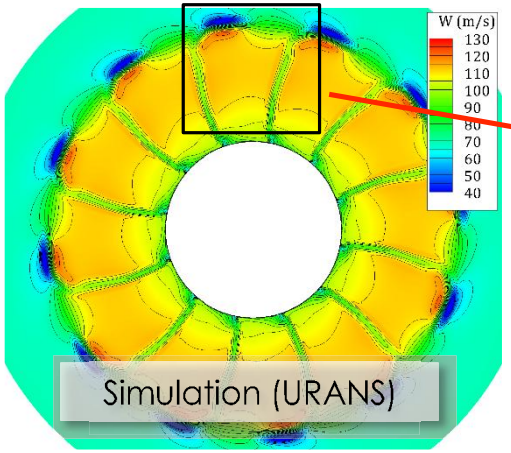


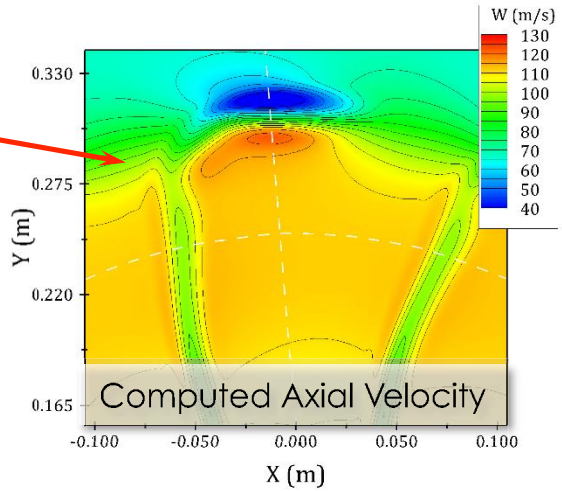
Rotor Flowfield Measurement

- **Using 3-compoent PIV technique, the intra-rotor velocity field was mapped and the data were compared w. CFD.**

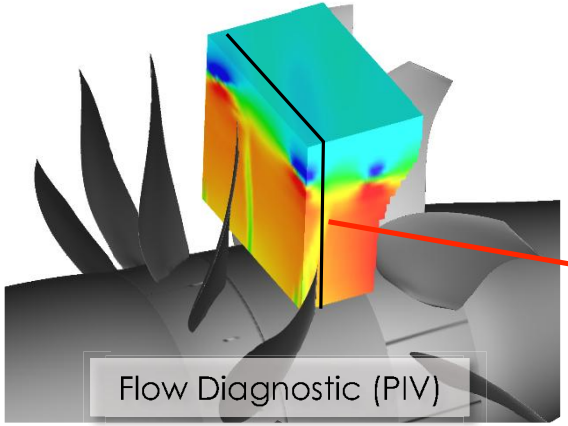
Simulation

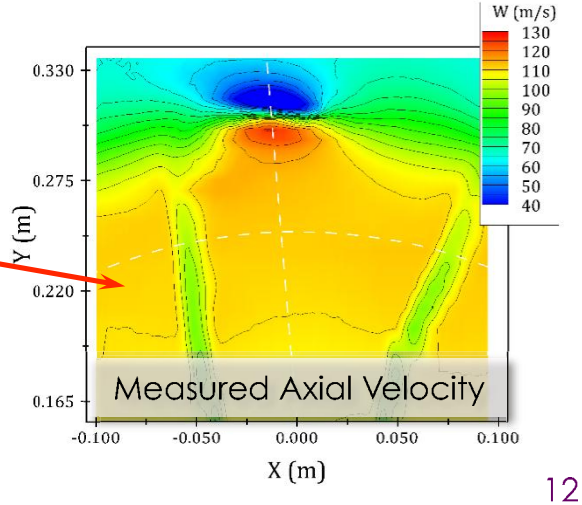






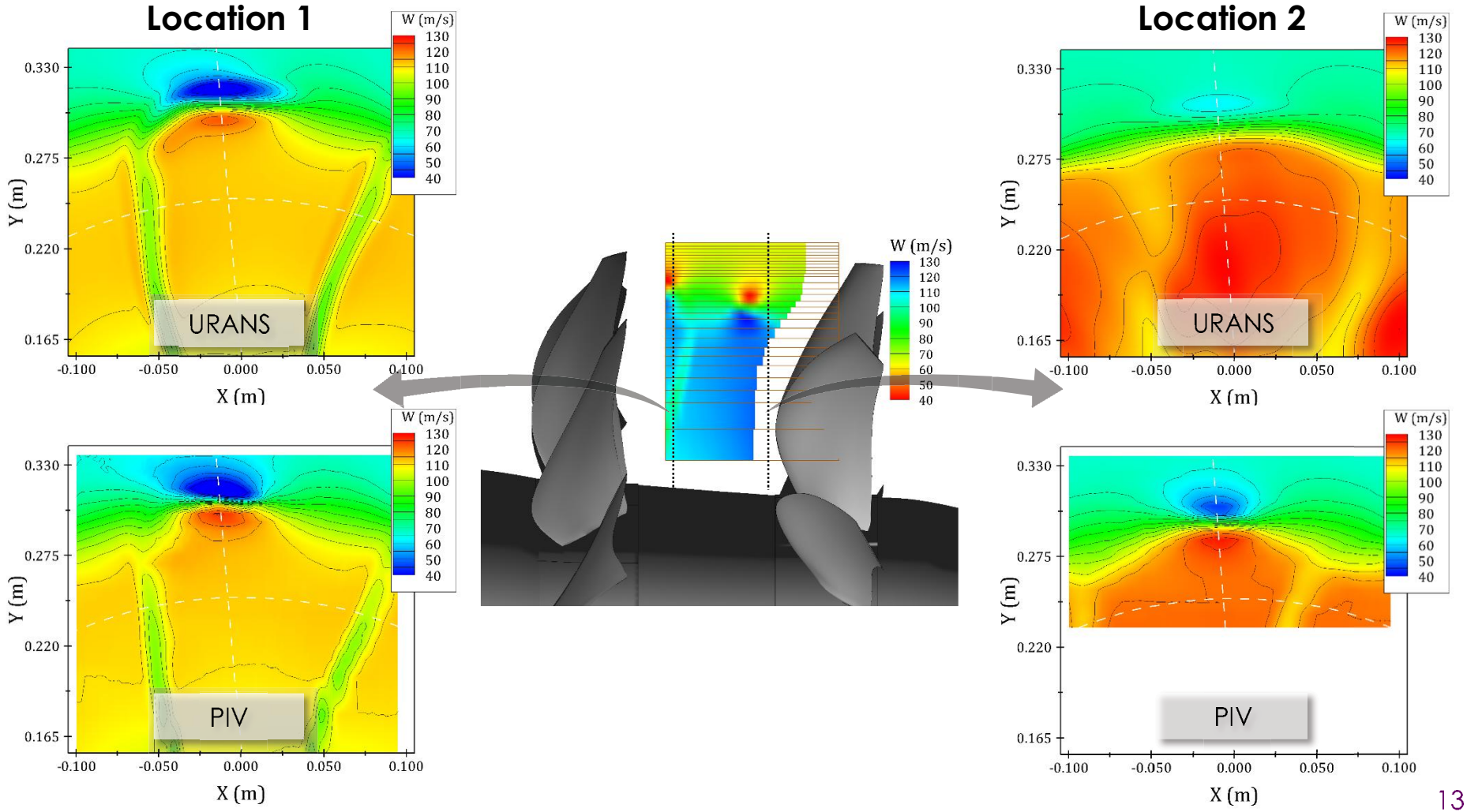
Experiment





Open Rotor Noise Modeling

- Comparisons were carried out at two axial stations, one near the front rotor and one near the aft rotor.



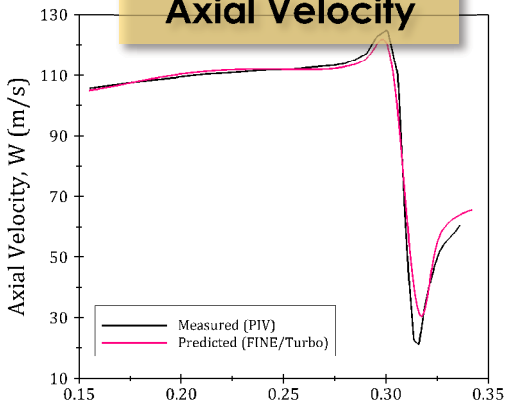
Open Rotor Noise Modeling

- Measurements indicated the strong influence of the rear rotor potential field on the wake of the front rotor. This could be the cause of interaction tone level discrepancies.

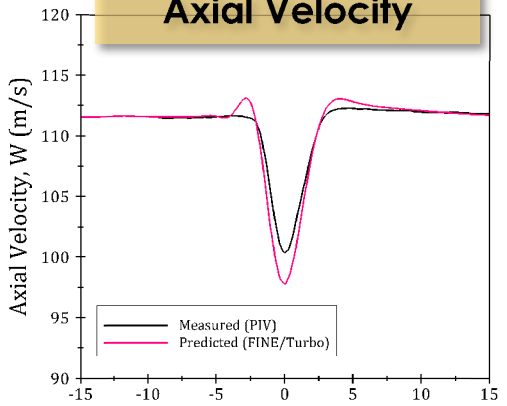
Location 1
(Near the Front Rotor)

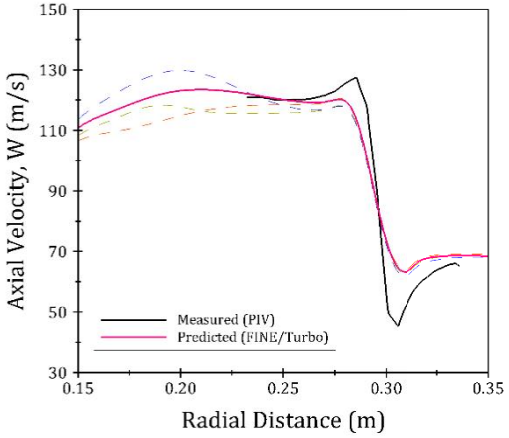
Location 2
(Near the Aft Rotor)

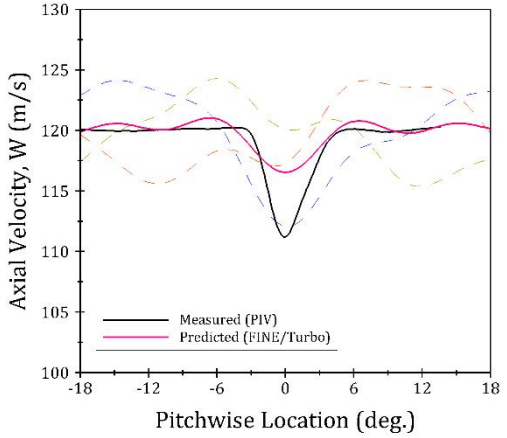
Radial Profile of Axial Velocity



Pitchwise Profile of Axial Velocity

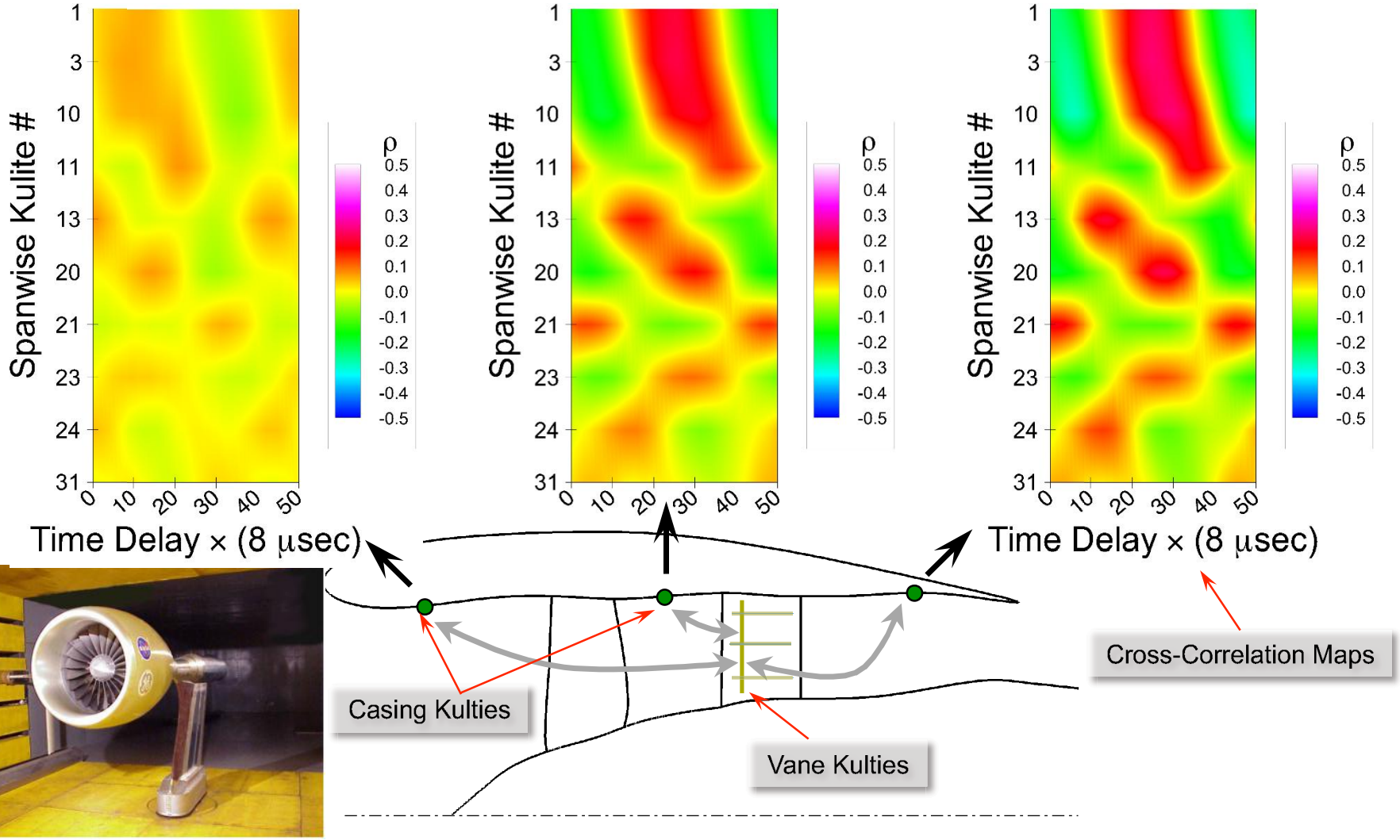






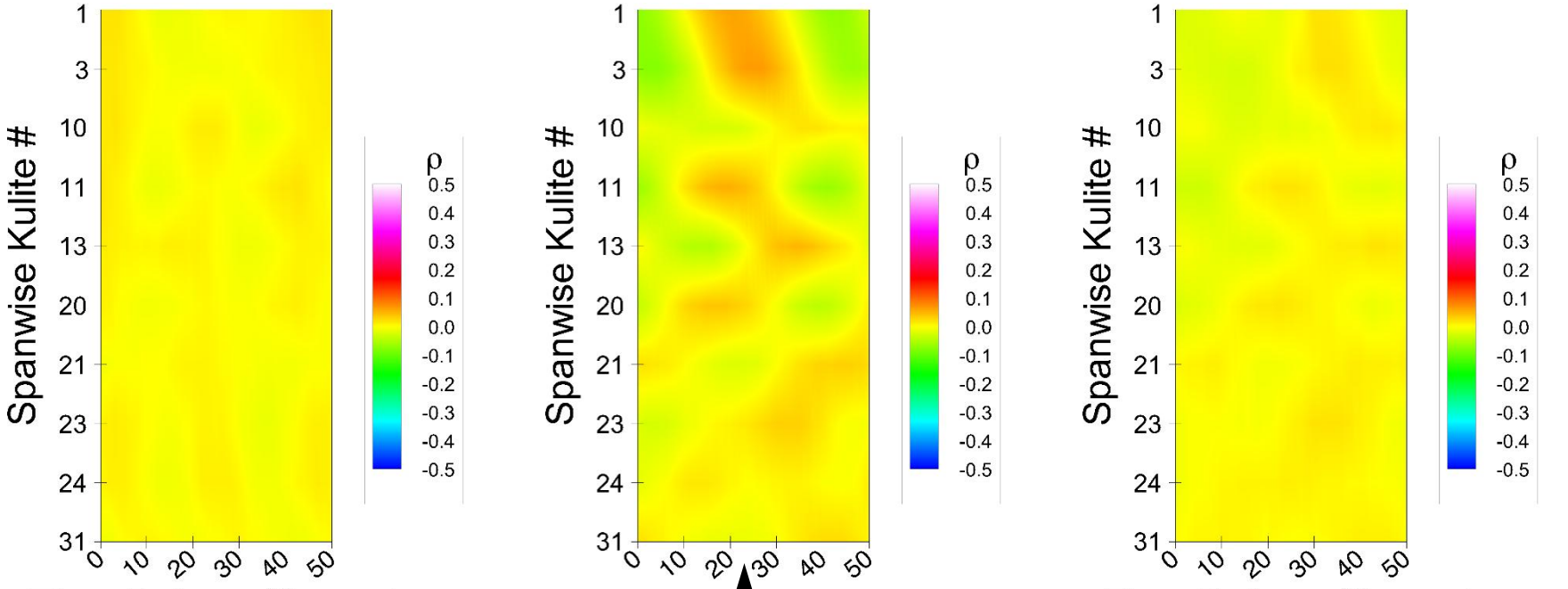
Noise Source Diagnostics

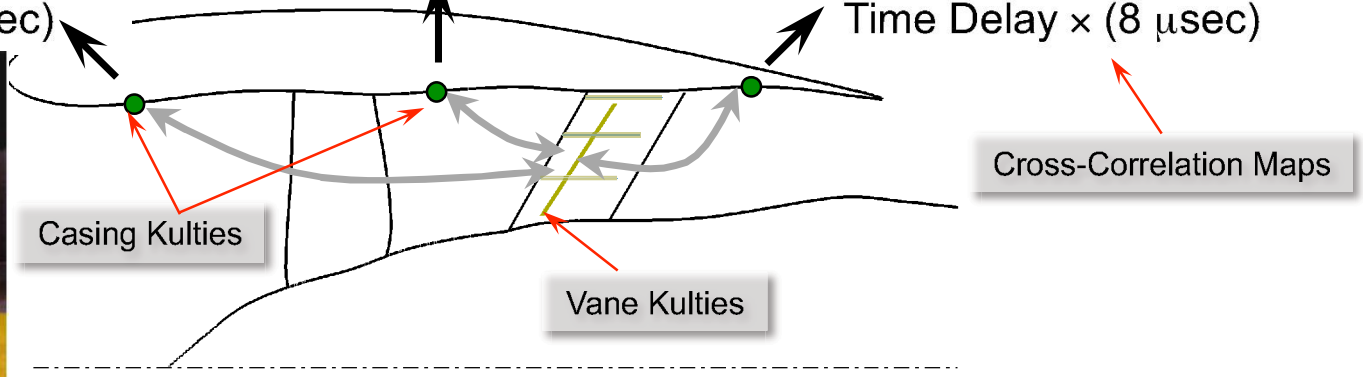
- In-Duct Analysis of Rotor/Stator Interaction Noise



Noise Source Diagnostics

- **Effect of OGV Sweep on Tone Noise**

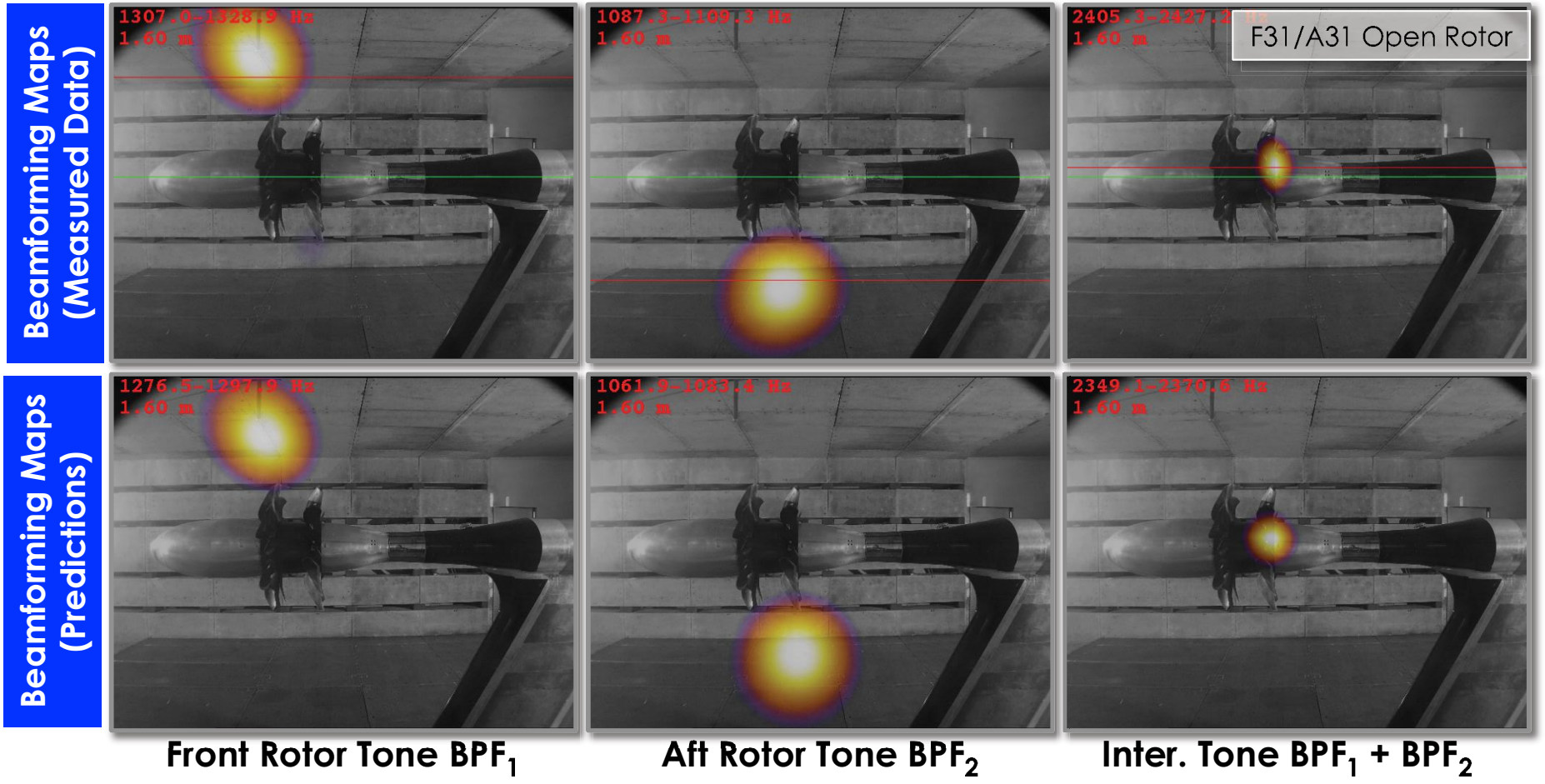




Modeling/Diagnostics Synergy

- **Prediction can provide insight for understanding the measurements.**

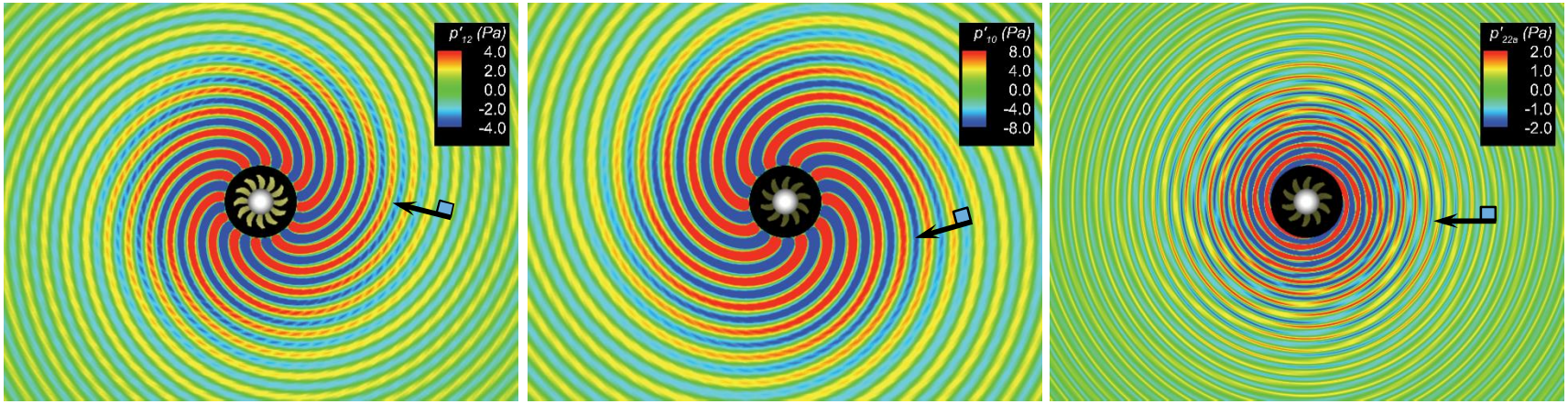
Low Speed
Wind Tunnel Test



Modeling/Diagnostics Synergy

- Computed acoustic field provided the clue for interpreting the phased array maps.

Wavefronts (Predictions)



Beamforming Maps (Predictions)

Front Rotor Tone BPF_1 | Aft Rotor Tone BPF_2 | Inter. Tone $BPF_1 + BPF_2$

Summary

- **Flow diagnostics …**
  - **are invaluable in assessing modeling strategies/tools for predicting noise from realistic turbomachinery components.**
  - **provide information that can be used to troubleshoot noise prediction tools and isolate the shortcomings of aerodynamic and/or acoustic models.**
  - **can be used to validate (or disprove) accepted noise generation mechanisms.**
  - **should be used synergistically with modeling tools to gain insight into the predicted or measured results.**

Questions?